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## *No. 10A Remote Switching System:*

# Transmission Plan

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*The transmission properties of a switching system always play an important role in the design of any switching system. This was particularly true in the design of the 10A Remote Switching System which has an architecture that raises new transmission problems. This paper describes these new problems and details the methods by which they were solved.*

## I. INTRODUCTION

The design of the 10A Remote Switching System (RSS) has involved the interaction of many disciplines and required the solving of many old and new problems. One of these traditional questions concerned the transmission performance of the switching path. It must be assured that the switching path contributes little to the transmission impairments of the overall end-to-end talking connection. While the design of the RSS must continue to meet this requirement, the question must be answered in a new light since RSS is an "extension" of its controlling host RSS and located some distance from it. This paper addresses the transmission issues associated with the host-RSS link, spelling out the objectives and requirements, detailing the actual plan, describing the methods of analyzing and evaluating the plan, and defining its characteristics.

## II. OBJECTIVES AND REQUIREMENTS

In this section, we describe various aspects of the design of RSS which had an impact on the development of the transmission plan. For a more detailed description of the RSS, see Ref. 1.

### 2.1 Extension of its host

The RSS, by design, is considered an extension of the host which controls it and on which it homes. This implies that lines served by the RSS be given the same kind of service as those lines served by the host directly. A customer served by the RSS should experience about the same transmission grade of service as would be experienced by a customer served directly by the bost. This is an *absolute requirement* when RSS replaces a class 5 Community Dial Office (CDO). In this case, the loops on the CDO could have been designed to the limits of a conventional class 5 office, and the link between the CDO replacement and the class 5 host should not add additional impairments which might affect DDD transmission. This transparency characteristic is *desirable* for pair-gain applications because, even though the transmission link replaces designed loss in the loop, significant savings can be obtained using finer gauge cable than would be required if the RSS subscribers were served directly by the host.

### 2.2 Choice of host class

As a way of assuring wide deployment of the RSS, it is important that the transmission plan be designed so that the RSS can be hosted from any local electronic switching system. In other words, the plan should not require that the RSS be hosted only by class 4 or combined class 4/5 offices.

### 2.3 Singing and echo performance

By forcing the transmission link to be transparent from a loss point of view, some form of amplifying equipment is needed. This gain can be supplied by unidirectional or bidirectional amplifiers. In either case, instability is a potential problem.

One choice of carrier facilities could be unidirectional amplifiers, commonly known as a 4-wire facility. Since both ends of the link are 2-wire (the subscriber end and the host end), standard methods of converting between 2- and 4-wire facilities using hybrids are required. Raising the gain in each direction to satisfy the transparency requirement mentioned earlier increases the probability that the connection will oscillate or sound hollow because of the feedback mechanisms of the 2- to 4-wire conversions, unless corrective measures are taken. The transmission plan must provide these corrective measures so that the transmission paths exhibit adequate echo performance.

### 2.4 Distance objectives

For this system to be economically viable, any restraints imposed by the transmission plan must be generous enough to allow the RSS to be *at least* 50 miles from its host.

### 2.5 Type of facilities

As indicated in a companion paper,[1] RSS will be deployed in various applications, e.g., as a replacement for CDOs and as an economic alternative to cable (pair gain). As a result, the RSS should be able to be served by as many different types of carrier facilities as possible, including both digital (e.g., T1) and analog (e.g., N) types, particularly to take advantage of in-place plant.

### 2.6 Interface with real loops

The plan must be workable and provide adequate performance even in the face of a real loop plant which does not conform exactly to design rules for a variety of reasons, including economic and maintenance. Design rules for loop plant include constraints on resistance, load coil spacing and deployment, and constraints on allowable bridge taps. As the loop plant is reconfigured to satisfy customer requirements, variation from the design rules can occur.

### 2.7 Easa of administration and maintenance

The plan must be straightforward and use simple methods for administration and maintenance. The ultimate goal should be that the RSS satisfy its own needs for information (e.g., condition or type of subscriber loop) rather than relying on manual methods, and use maintenance methods that are triggered and executed automatically.

## III. THE RESULTING PLAN

### 3.1 Zero-dB link

The RSS transmission plan centers around 0-dB links from the line appearance at the RSS to the ESS line link network appearance of the channel. (See Fig. 1.) From a transmission loss standpoint, the RSS line effectively appears as a line at the ESS.

### 3.2 Improved impedance match

Previous implementations of 0-dB plans have often had problems because the resulting 2- to 4- to 2-wire paths were frequently poor transmission links. Connections using these links might be graded as poor by customers because they would sound "hollow"* or, even worse, they might be unstable and oscillate or squeal in the customer's ear. This condition results from the fact that signals starting at $A$ (see Fig. 2) and arriving at the input of the 4-wire port of hybrid 1 would "leak across" the hybrid and return via its transmit port back to hybrid 2. If

* Hollowness on telephone connections is typically referred to as listener echo. Loss in the closed loop formed by the 2- to 4- to 2-wire path is defined as listener echo path loss.

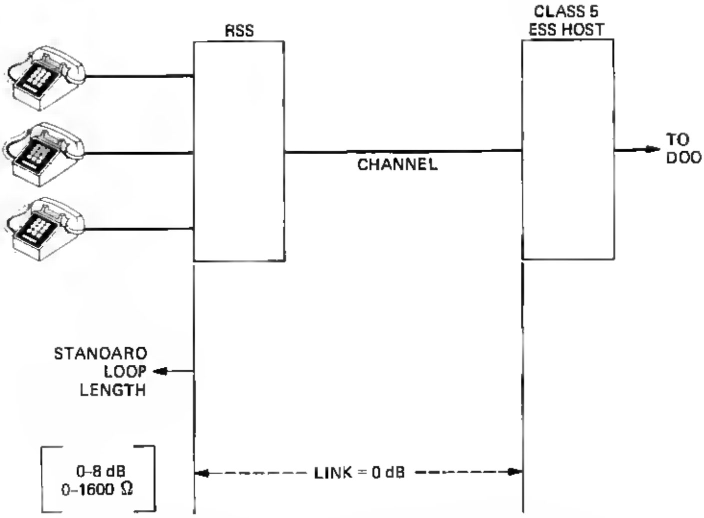


Fig. 1—Remote switching system transmission plan basic objective.

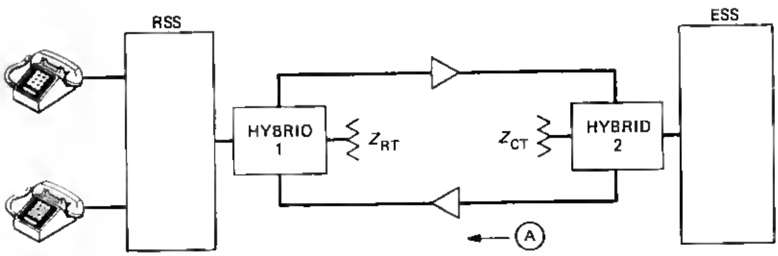


Fig. 2—Remote switching system transmission link.

the signal also leaks across hybrid 2 such that it returns to $A$ at the same or greater energy than it began, oscillation (or singing) can occur. Oscillation can be prevented by decreasing the gain in either (or both) directions, or by increasing the loss across one (or both) hybrids. Because we must keep the loss from one end to the other at 0 dB, we are not free to decrease the gain of either amplifier. Therefore, techniques for increasing the transhybrid loss at the 2- to 4-wire interfaces were established. The most straightforward approach is to choose a better impedance compromise network for the overall loop population. It has been determined[2] that a single, parallel resistor-capacitor compromise network provides a better impedance match to the overall Bell System loop population than does the standard 900 ohm in series with 2.16-$\mu$F network. In addition, it has also been determined that further improvements in impedance matching and, hence, return loss can be gained by using separate parallel RC balance networks for

loaded and nonloaded loops. The use of separate balance networks for loaded and nonloaded loops is generally called loop segregation.

To improve stability and listener echo performance on the RSS-host channel, the RSS has adopted the improved balance networks. The channel units at the remote end of the RSS-host channel are equipped with switchable balance networks for loaded and nonloaded loops. The appropriate balance network is inserted on a per-call basis. The loaded-nonloaded decision is made automatically by a new circuit called the Electronic Loop Segregator (ELS). See Section 3.3 and the Appendix for more details.

At the host end of the channel, it is impractical to implement a device like the ELS in existing analog offices since there is no convenient place in the host network topology to place the loop segregator circuit and minimize per-call usage of host resources. Therefore, a single compromise network is used to match all types of terminations. The most difficult to match impedances at the host office are the lines served by the host. Therefore, the RSS channel unit at the host uses an impedance compromise network. This results in an improvement in return loss for connections to host lines and provides adequate return loss for connections to direct and toll connecting trunks.

### 3.3 Electronic Loop Segregator

The separation of loops into the two categories of loaded and nonloaded loops is done by the RSS system using the ELS. This circuit is used in the following way:

(*i*) At least once a day, a measurement of the ac impedance of each on-hook line is made. The real part of this impedance is compared to a threshold. The result of this comparison is stored in RSS memory with 1 bit per line.

(*ii*) When the line goes off-hook on a terminating or originating call, the proper balance network is chosen for the RSS end based on the above measurement. If the real part of the impedance is above the threshold, the loop is assumed to be loaded, and the loaded network is selected. If the real part of the impedance is below the threshold, the loop is assumed to be nonloaded, and the nonloaded network is selected. (If the loop is misdesigned, ELS usually chooses the best match.)

### 3.4 Maintenance aspects

To retain the improved transmission performance that the modified balance networks provide, all the parameters of the elements in the transmission paths must be chosen to have a minimal variation. This has been guaranteed for each end of the link by choosing components with minimal variation and by assuring that the variations in the gains

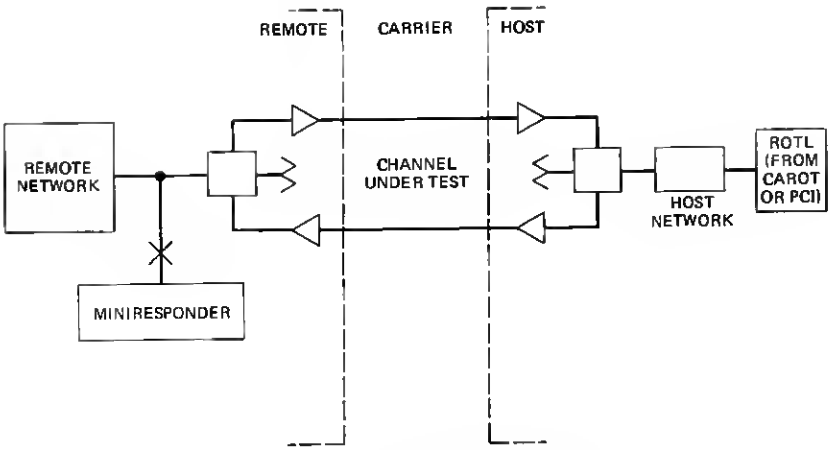


Fig. 3—Remote switching system channel testing.

of the amplifiers be limited. For this plan, we have required this variation to be limited to ±1 dB.

The maintenance of the channels from both an operational and transmission perspective is done from the host, and uses techniques similar to those used to maintain operational and transmission performance on trunks. Included in the RSS frame is a miniresponder circuit which has metallic access to the network side of each channel. (See Fig. 3.) The host, under control of automated transmission test systems [centralized automatic reporting on trunks (CAROT) or program controlled interrogator (PCI)], will establish a test call to the responder from the ESS and will use the channel under test. Conventional loss and noise measurements will be made in each direction. The $Q1$ level (the gain/loss band outside of which a report is made to the maintenance craft) is about 0.7 dB, and the $Q2$ level (the gain/loss band outside of which the channel is removed from service) is about 0.9 dB. The choice of these values is influenced by the measurement accuracy of the test equipment which is ±0.1 dB.

### 3.5 *Provisions for trouble loops*

As will be shown later in this paper, the above plan works well even in the face of most real loops that do not necessarily meet the conventional resistance design requirements. As a backup measure, however, a feature has been included to allow the RSS to work temporarily with a loop that is grossly different from the design requirement. Loops with this characteristic need to be repaired, but can be made to work temporarily until maintenance craft can be routinely dispatched. On a temporary basis, the RSS has the capability of

inserting 2-dB loss in each direction of a channel connected to a loop. The system will perform this loss function if a specified bit per line is set. The bit is set (or cleared) by a TTY message initiated by a craft person. The bit is not controlled autonomously by the system. This loss state will be temporary; ultimately, the problem loop must be fixed.

## IV. EVALUATION AND ANALYSIS METHODS

When the plan was designed, it was clear that the various aspects of the plan provided improvements to the transmission quality, but it was not clear whether enough improvement was achieved. This section describes the various methods used to analyze and evaluate the plan.

### *4.1 Subjective testing*

A zero loss 2- to 4- to 2-wire connection has the potential of singing if the energy circling around the 4-wire path is sufficiently high to sustain oscillations. However, even if a connection is not singing but is close to singing, the transmission performance would not generally be considered acceptable to most customers. This characteristic is called "near singing distortion" or "listener echo." Objectively, near singing creates ripples in the net 2- to 2-wire response of the system. The ripples can be characterized by the magnitude and frequency shape of the loss in the feedback path, plus the round-trip delay in the 4-wire portion of the system. Subjectively, near singing manifests itself as an unnatural or hollow effect which can, in some cases, make a conversation sound as if it is being conducted in a drainage pipe.

To quantify the effects of near-singing distortion, subjective tests were conducted (Ref. 3). The tests independently varied listener echo path loss, round-trip delay, and frequency response of the 4-wire path. As a result of these tests, a new measure of subjective quality has been defined: Weighted Echo Path Loss (WEPL). The WEPL provides a more accurate view of connection quality than does singing margin. The WEPL concept is demonstrated in Fig. 4. The measure is based on an average (versus frequency) of the loss around the closed loop (listener echo) path. Because of the averaging, WEPL provides a less conservative view of connection quality than singing margin. Use of WEPL for judging subjective quality allows more meaningful objectives for the control of listener echo to be established.

One of the most important parameters when evaluating performance is the round-trip delay of the system. Listener echo becomes increasingly objectionable with increasing delay. Correspondingly, the value of WEPL required to provide adequate connection quality increases with increasing delay. Thus, current WEPL objectives are stated as a function of round-trip delay in the 4-wire path. A comparison of the

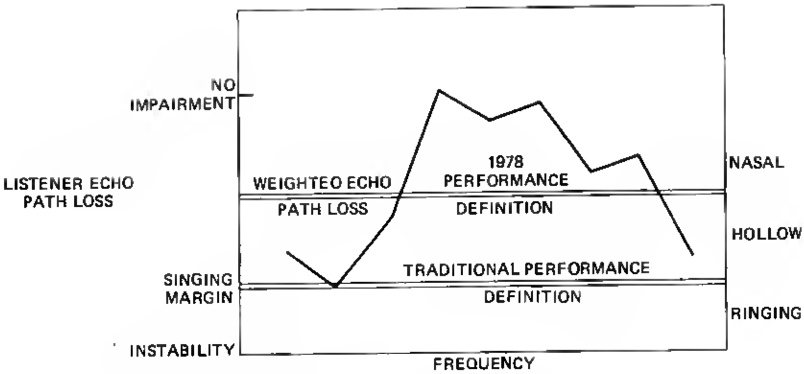


Fig. 4—Singing margin and weighted listener echo path loss.

WEPL objectives and the predicted WEPL performance for a distribution of connections can be used to establish the allowable delay in the system. For example, the WEPL objectives for a distribution of connections with round-trip delays of 4 and 7 ms are shown in Fig. 5. For a system with a 4-ms round-trip delay to provide acceptable listener echo performance, the WEPL performance for a distribution of connections made over the system must exceed (i.e., be to the right of) the 4-ms WEPL objective. Similarly, the 7-ms distribution must be met or exceeded by connections with a 7-ms round-trip delay. Recommended distributions of WEPL performance for other delays have also been established (Ref. 3).

Knowledge of the allowable round-trip delay can be used to form limits on signal processing delays and to set length restrictions for remote-host transmission lengths. The remote-host length restrictions for the RSS system are discussed in Section V.

### 4.2 *Evaluation using various loop populations*

Once the subjective tests had been used to establish transmission objectives for achieving customer satisfaction, it was necessary to determine how the RSS performed with its transmission plan. This was done by performing a computer simulation based on a model of the RSS transmission characteristics and a data base which contained the impedance of the subscriber loops. The model included the transmission characteristics of the switched path from the line appearance of the subscriber on the RSS to the 2-wire channel appearance at the host ESS. The model was more complex than models of previous ESS systems because the RSS contains more components affecting the transmission paths than earlier systems. With the model created (together with the expected worst-case tolerance of each part), the performance of RSS

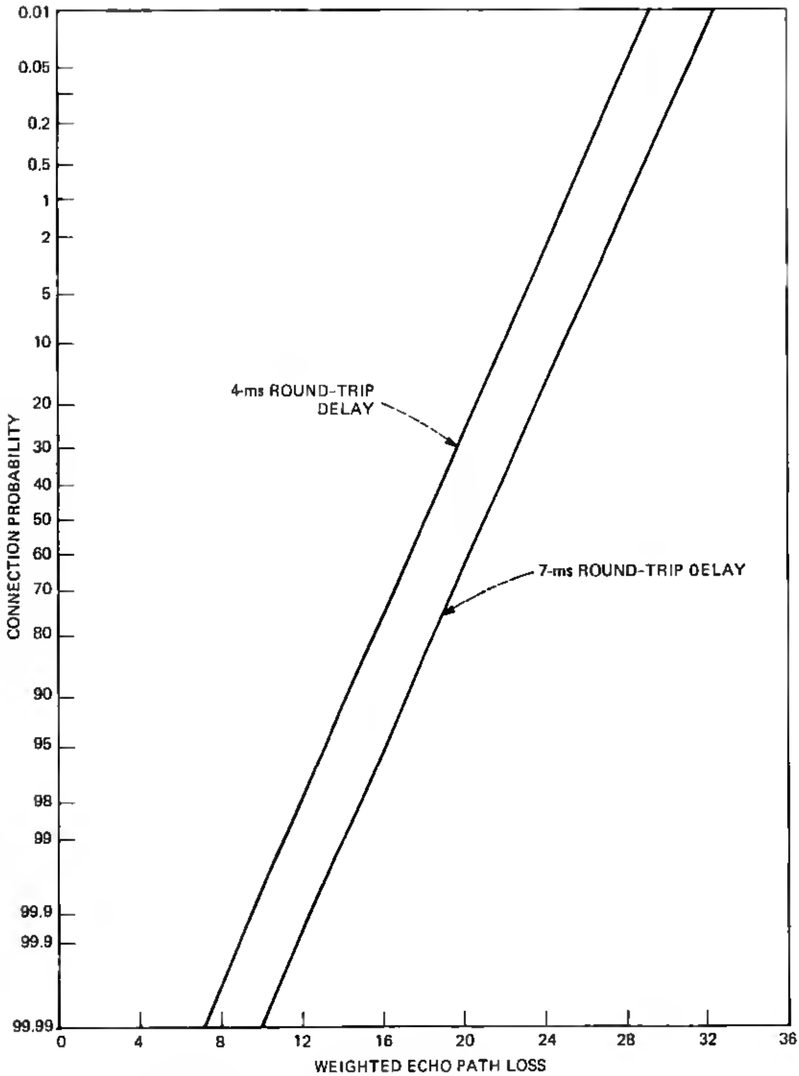


Fig. 5—Weighted echo path loss objectives for 4- and 7-ms round-trip delay.

for loss and WEPL was determined by simulating connections where terminations at the 2-wire points were real loop impedances. The simulation involved choosing two loops from the population, placing one at each end of the connection, and calculating loss and WEPL for that connection. This process was repeated for all possible connections involving all loops in the data base. Cumulative distribution functions of WEPL performance were then generated and compared with the requirements.

The evaluation of WEPL performance for the RSS was completed using two different data bases of customer loops. The first data base came from the 1973 survey of Bell System loops (Ref. 4). This data base contained 1098 loops sampled from all varieties of real loops on working switching systems. These survey data were based on paper records only. The second data base came from a 100-percent sample of the loops served by one of the first RSSs placed in service. This data base contained 625 loops, and was generated by using paper records

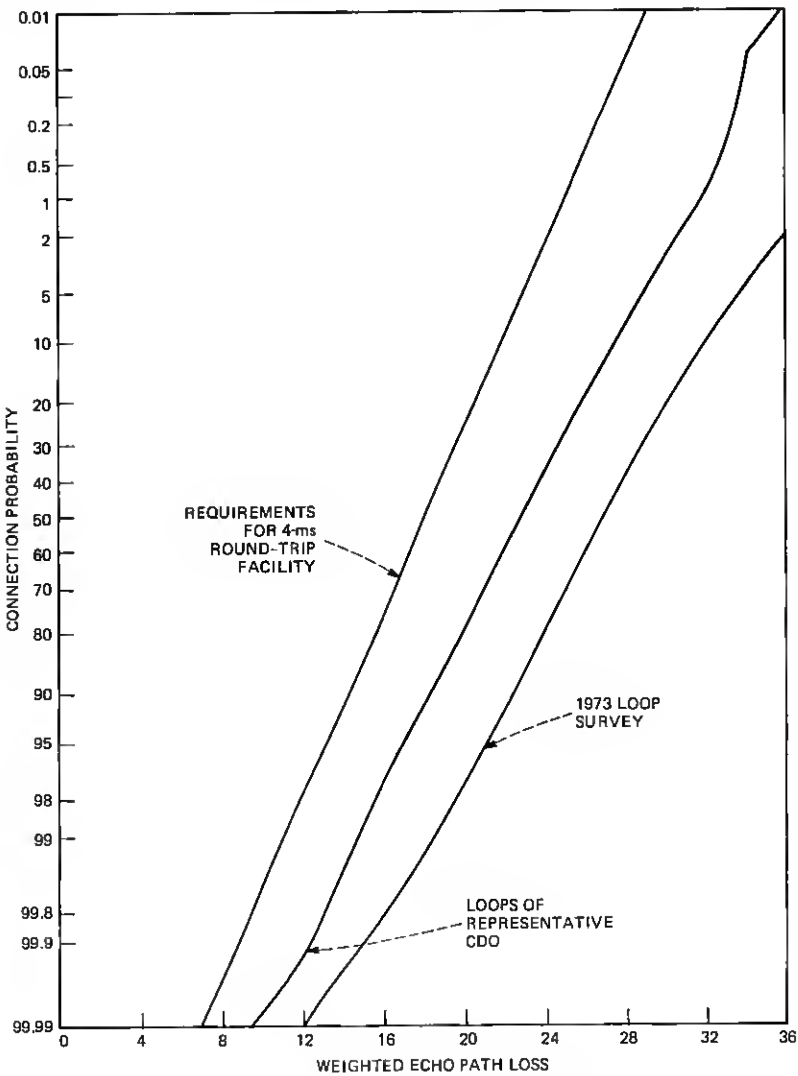


Fig. 6—Weighted performance with RSS.

and electrical testing of each loop. It is expected that this office is typical of many Bell System CDOs.

The WEPL performance using the CDO data base was not as good as the performance using the 1973 survey data base. (See Fig. 6.) However, performance for both surveys met the WEPL requirements for a system with 4-ms round-trip delay. This level of performance of a CDO population is significant because the CDO data base contained a large number of loops that did not strictly adhere to resistance design rules. This WEPL performance level implies that wholesale changes are *not* required when an RSS is placed into service, even though there are a number of other reasons that loop plant should be improved, independent of the installation of the RSS.

## V. CHARACTERISTICS

### 5.1 Limitations on facility types

Because of the requirement (in Section 3.4) that the variation of gains be limited to ±1 dB, only the more modern carrier types are compatible with RSS. Specifically, RSS will be able to interface with T1 digital lines, N2, N3, and N4 analog lines, and analog radio facilities that use A5 or A6 banks. The A-banks must be equipped with compandors to assure quality signal-to-noise performance.

### 5.2 Distance limitations

As is shown in Section 4.2, the transmission link is limited in distance by the round-trip delay of the facility. This round-trip delay is limited to 4 ms (averaged over the frequency band). All components that contribute to the delay must be accounted for, including the multiplexing terminals at each end, as well as the propagation delay over the transmission medium. These parameters vary with facility types. The following lists the distance limitations by facility type:

| | |
|---|---|
| T carrier via repeatered metallic lines | 175 miles |
| T carrier via digital radio | 260 miles |
| N2 carrier via repeatered metallic lines | 150 miles |
| N2 carrier via analog radio | 280 miles |
| N3, N4 carrier via repeatered metallic lines | 75 miles |
| N3, N4 carrier via analog radio | 140 miles |
| A5, A6 banks with compandors via radio | 140 miles |

## VI. SUMMARY

The RSS is now providing service to customers in Clarksville, New York, as well as in over 50 other locations around the country. Performance from both a switching and transmission perspective has

been very satisfactory. The transmission plan that has been presented above has met all the goals and objectives that were set forth.

## VII. ACKNOWLEDGMENTS

The evaluation of the 10A RSS transmission plan has involved the work and advice of many people in Bell Laboratories and AT&T. We would like to acknowledge the contributions of W. L. Ross, J. R. Rosenberger, III, R. W. Hatch, J. L. Sullivan, A. M. Lessman, G. M. Cofer, and D. L. Whitney.

## APPENDIX

### *Techniques for Loop Segregation Using ELS*

A scheme for improving singing margin and echo performance through the use of loop segregation is meaningless unless a simple means of distinguishing between loaded and nonloaded loops is available. Separating loaded from nonloaded loops can either be done on paper (through office records), or by an electrical measurement. The paper approach is hazardous because using office records is not as accurate as electrical measurements and could commonly lead to the wrong choice for a compromise network. The most common electrical measurement which can distinguish between loaded and nonloaded loops is the level trace meter. However, there are other simpler measures which can be employed. These measures are based on the fact that one of the most significant electrical differences between loaded and nonloaded loops is in the real part of the loop impedance near the upper band edge. These differences occur for both on-hook and off-hook measurements. However, the customer may be bothered by measurements on the loop while the telephone receiver is at the customer's ear. Also, off-hook measurements may experience difficulties because of interference from the customer's voice or ambient noise at the subscriber location. Therefore, the RSS has adopted an algorithm for loop segregation based on an electrical measurement of the on-hook impedance. Fig. 7 shows a scatter diagram of on-hook loop driving point impedance at 3200 Hz for loops from the 1973 Bell System customer loop survey. Different symbols have been used for loaded and nonloaded loops. Note that there are differences between the two populations which can be exploited. Table I shows the result of a search for a loaded-nonloaded decision criterion based on the real part of the on-hook impedance. A threshold setting between 400 and 540 ohms results in a loaded-nonloaded accuracy of 98.7 percent. Almost all of the mistakes are loaded loops matched with nonloaded balance networks. They are primarily short single-load coil loops which should not have been loaded.

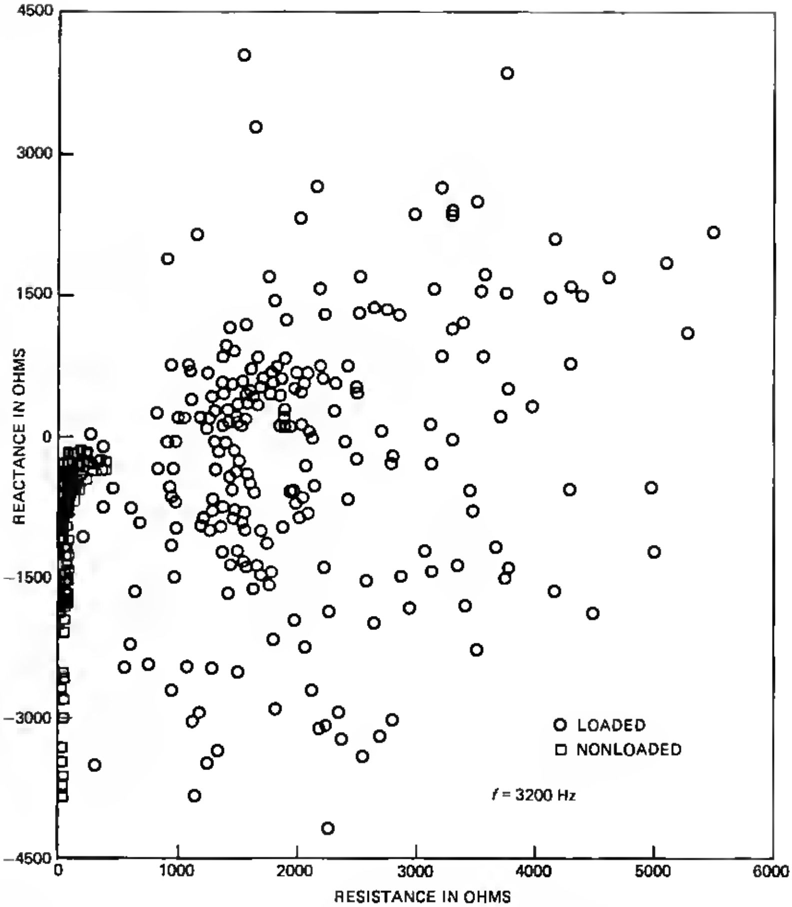


Fig. 7—Bell System loop survey—loop driving point impedance (3200 Hz) on-hook 500 set.

The following paragraphs give an overview of the circuit arrangements to do this segregation. The standard way to measure an unknown impedance (such as that of the loop which we wish to characterize) is shown in Fig. 8. A current of known level and frequency is applied, and the resulting voltage is measured. This works well if the unknown impedance ($Z_x$) is passive. However, any noise from the unknown impedance shows up in this voltage. The obvious solution is to filter $V$ at the same frequency as the current source. (See Fig. 9.)

This will block the noise unless the noise falls in the pass band of the filter. As we boost the $Q$ of the filter, less noise can pass. This works well as long as the current source frequency remains in the filter's pass band. One can see that as the bandwidth gets smaller, the alignment of the oscillator and the filter becomes critical.

Table I—Threshold values for loaded-nonloaded segregation based on real part of 3200-Hz on-hook impedance

| Real Impedance | Number Mistakes | Number Loaded Assumed Nonloaded | Number Nonloaded Assumed Loaded |
|---|---|---|---|
| 300 | 178 | 9 | 169 |
| 320 | 138 | 11 | 127 |
| 340 | 106 | 11 | 95 |
| 360 | 68 | 11 | 57 |
| 380 | 40 | 13 | 27 |
| 400 | 14 | 13 | 1 |
| 420 | 13 | 13 | 0 |
| 440 | 13 | 13 | 0 |
| 460 | 14 | 14 | 0 |
| 480 | 14 | 14 | 0 |
| 500 | 14 | 14 | 0 |
| 520 | 14 | 14 | 0 |
| 540 | 14 | 14 | 0 |
| 560 | 15 | 15 | 0 |
| 580 | 15 | 15 | 0 |
| 600 | 15 | 15 | 0 |
| 620 | 17 | 17 | 0 |
| 640 | 18 | 18 | 0 |
| 660 | 18 | 18 | 0 |
| 680 | 18 | 18 | 0 |

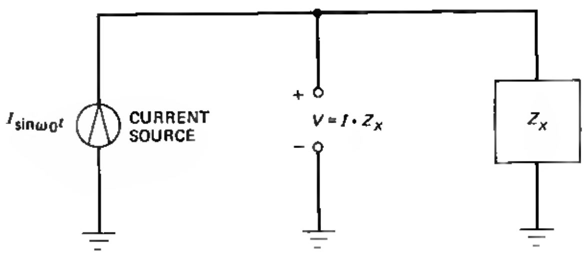


Fig. 8—Standard impedance measurement technique.

Fig. 10 shows the details of the problem. Here, one Band Pass Filter (BPF) is used as an oscillator and another one is used to filter the current related to the unknown impedance. Ideally, the two filters should be identical. One way to keep the two filters close is to build them from crystals. This could be done, but at 3200 Hz, it would be difficult and expensive. Besides, what is needed is not a precise frequency—only tracking filters.

The best way of making two filters track is to make them one filter. If the same filter can be used to generate the oscillations and filter the resulting voltage, the filter's $Q$ can be made very large.

Figure 11 displays the circuit configuration using only one filter. There are three functions present. First there is the high $Q$, two-pole,

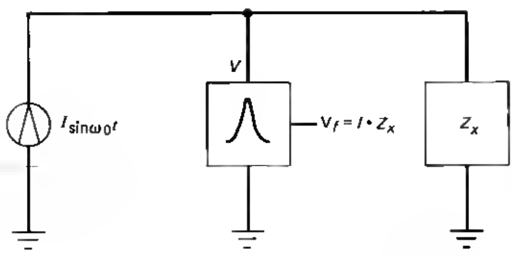


Fig. 9—Impedance measurement which reduces effects of noise.

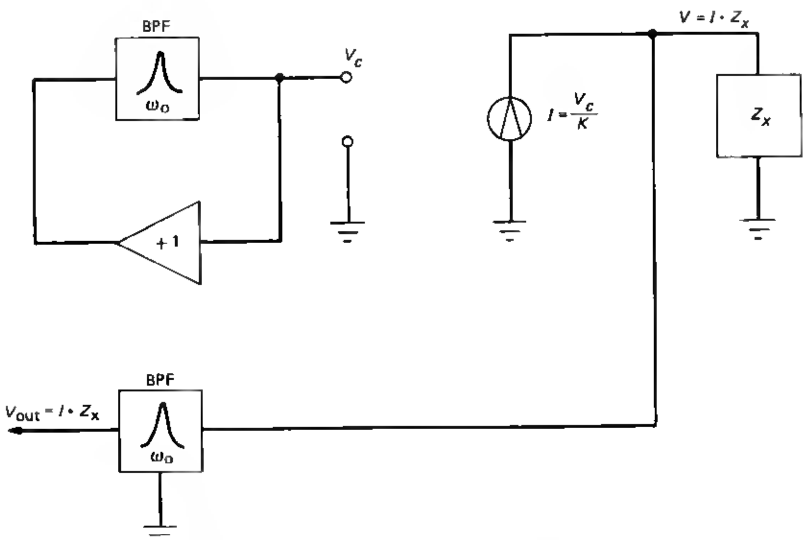


Fig. 10—One form of implementing Fig. 9.

BPF. Added to this is the Voltage Controlled Circuit Source (VCCS). The comparator completes the circuit.

If we assume that the BPFS output voltage, $V_{out}$, is a sine wave at a given frequency, then the output of the comparator, $V_c$, will also be at the same frequency. Furthermore, it will be in phase with $V_{out}$. The VCCS will also be in phase with $V_{out}$.

The test current out of the VCCS is applied to the unknown impedance $Z_x$. The resulting voltage is applied to the filter. It is at the same frequency and out of phase with the test current by the phase angle of $Z_x$. The input voltage to the filter is equal to the test current times the unknown impedance. Note that a phase difference has been forced across the filter. $V_{out}$ is, by definition, 0 degrees; $V_{in}$ is determined by

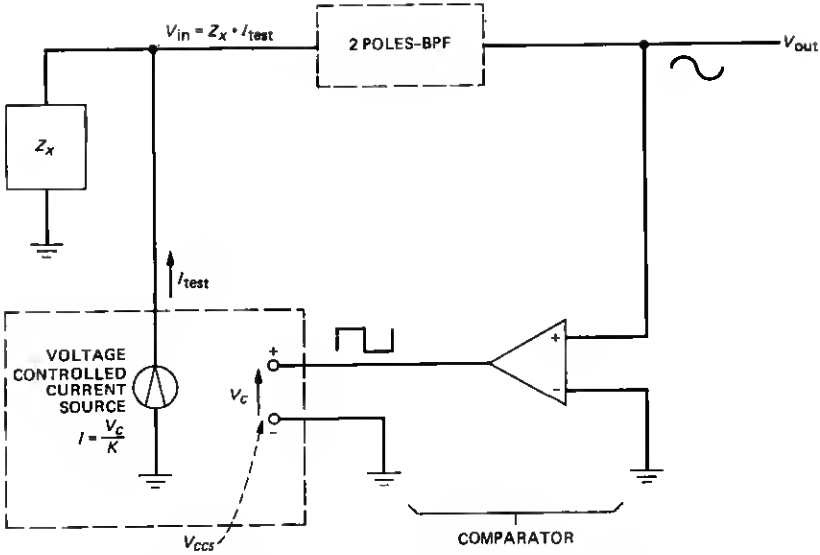


Fig. 11—Improved way of implementing Fig. 9 using single filter.

$Z_x$'s phase. The BPF is forced to exhibit a phase difference equal but opposite to the unknown's phase. Once this occurs, the sum of the phases around the signal path become 0 degrees. The frequency of oscillation adjusts itself to satisfy this condition.

In the above discussion, it was assumed that all voltages and currents were sine waves. Note that the comparator's output is really a square wave. This forces the test current to also be a square wave. A square wave contains odd harmonics, as well as the fundamental. However, only the fundamental frequency passes through the high-$Q$ BPF. It is, therefore, valid to treat all signals as pure sine waves.

The circuit will oscillate as long as the sum of the phases equals zero. The two-pole BPF can exhibit phases from −90 degrees to +90 degrees. This means an unknown impedance must not exceed ±90 degrees. All telephone loops satisfy this condition.

It can be shown that the magnitude of $V_{out}$ of Fig. 11 is proportional to the real part of the unknown impedance, $Z_x$.

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